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ADVANCE CONFIDENTIAL REPORT #248

DETERMINATION OF FLIGHT PATHS OF AN SBD-1 AIRPLANE

IN SIMULATED DIVING ATTACKS

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SUMMARY

An investigation has been made to determine the motions of and the flight paths described by a Navy dive-bombing airplane in simulated diving attacks. The data necessary to evaluate these items, with the exception of the atmospheric wind data, were obtained from automatic recording instruments installed entirely within the airplane. The atmospheric wind data were obtained from the ground by the balloon-theodolite method.

The results of typical dives at various dive angles are presented in the form of time histories of the motion of the airplane as well as flight paths calculated with respect to still air and with respect to the ground.

INTRODUCTION

Records have been obtained for a number of simulated diving attacks made with a Douglas SBD-1 airplane. Instruments necessary to record flight-path data were installed in the airplane and tests were made at Langley Field, Va. Flight tests consisting of a total of 18 dives were made on October 19, 1942 and October 20, 1942. The tests were made by two pilots from the Dahlgren Naval Proving Ground each of whom made nine dives covering dive angles ranging from approximately 45° to 75°. The two Navy pilots are designated pilot A and pilot B throughout the paper. Data recorded during the test dives have been evaluated by NACA personnel, and data from six typical dives are presented herein.

INSTRUMENTATION AND TEST PROCEDURE

Data were recorded in flight by the following NACA instruments, which were synchronized by a timer:

1. Airspeed recorder

2. Three-component accelerometer

3. Recording altimeter (including sensitive differential static-pressure recorder)

4. Rolling-velocity recorder

5. Pendulum inclinometer in pitch

6. Gryo inclinometer in pitch

7. 35-millimeter Eyemo horizon camera

8. 16-millimeter Ciné-Kodak Special horizon camera

The airspeed recorder was connected to an NACA free-swiveling static head mounted at the end of a boom extending a chord length ahead of the right wing near its tip and to an NACA total-head meter located 3 feet behind and $4\frac{1}{2}$ inches below the static head. Lines used to transmit pressures from the heads to the recorder were balanced for lag in order that no error would be incurred in recorded airspeed because of rapid changes in altitude. No measurements were made of the time lag in recording airspeed because of changes in speed, but the time lag was calculated to be only about 0.1 second by the method presented in reference 1 and was therefore neglected.

The recording altimeter was opened to cockpit pressure in order to reduce lag and the records of the altimeter were corrected for the difference between cockpit pressure and airspeed static pressure as measured by a sensitive pressure recorder. Lines transmitting pressures to the pressure recorder were also balanced and the slight lag error calculated for the recording altitude system was likewise neglected.

The pendulum inclinometer was used to determine refrence angles between the thrust axis and the horizontal for correlation with gyro-inclinometer and horizon-camera

data. For this purpose, short simultaneous records were taken on all instruments in straight level flight immediately before the dives were entered for most or all dives made in each flight.

The 35-millimeter Eyemo camera and its electric driving motor were enclosed in a dummy bomb attached to the bomb rack under the right wing. The 16-millimeter Ciné-Kodak Special spring-driven camera was mounted inside the fuselage behind the rear cockpit. Both cameras were lined up with the Y axis of the airplane and set to photograph the horizon to the right of the airplane throughout the dives. Ordinary panchromatic film was used in conjunction with a 4X red filter for penetrating haze.

In addition to the recording instruments listed, an electrical resistance-type thermometer was installed with its indicating dial on the pilot's instrument panel. Temperatures read by the pilot at each 1000-foot level during the initial climb for each flight were corrected for compressibility in order to obtain free-air temperature patterns used in correcting indicated to true airspeed.

Atmospheric wind data were collected by the balloon-theodolite method at the Norfolk Naval Air Station for times as near as possible to those at which dives were made. These data were used to determine space flight paths after flight paths relative to still air were known.

Flight tests consisted of nine dives by pilot A and nine by pilot B. Each pilot made three dives at 45°, three at 60°, and three at 75°. The dive angles were estimated by the pilots by visual means alone. Full diving flaps were used throughout the dives and rolling velocities were held to a minimum. Dives were entered, without rolling, from a direction so chosen that the sun was approximately over the left wing tip. This procedure fixed the direction of the dive in space so that atmospheric wind data could be correlated with air flight paths to obtain space flight paths and insured optimum light conditions for the horizon cameras.

RESULTS

A summary of airplane conditions and results obtained for all 18 dives are presented in table I. In figure 1 are shown atmospheric wind conditions measured over Norfolk, Va., at times nearest those at which flights were made. Figure 2 shows the data of figure 1 altered to give the component of wind velocity acting along the azimuth direction of the flight paths based on the assumption that all dives were made along the reference direction fixed by having the sun directly over the left wing tip. In the calculation of space flight paths, the further assumption was made that wind conditions during any dive were identical with those measured nearest the time of the dive. Figure 3 shows the free-air temperature readings plotted against the altitude readings, which were made in the test flights and subsequently used in correcting indicated to true airspeed.

Complete data for the six typical dives are presented as time histories in figures 4 through 9. The indicated airspeeds given in these figures were calculated from the relation

$$V_i = 45.08 \sqrt{q_c}$$

where q_c is the measured impact pressure in inches of water. The compressibility correction was applied in calculations made to obtain the curves labeled "True" in the plots of airspeed against time. Values of true and indicated airspeed given may be in error by about 1 percent at low angles of attack or about 2 percent at high angles of attack since no calibration was made of the airspeed system for error due to pitot-static-head positions. The error in recorded altitude due to static-head position is negligible. Accelerations shown were estimated to be accurate to within the following limits: normal, ±0.05g; longitudinal, ±0.04g; and transverse, ±0.03g. The attitude angles shown are those measured between the airplane thrust axis and the horizontal by either the gyro inclinometer or the horizon camera. Absolute angles of attack and flight-path angles relative to the air were calculated by the method explained in the following discussion.

Figure 10 shows instantaneous conditions existing in a dive as well as most of the items used in flight-

path calculations. For purposes of analysis, these items are defined as follows:

θ attitude angle defined as angle between thrust axis and horizontal as measured by horizon camera or gyro inclinometer

γ_A angle of air flight path with horizontal

α_a absolute angle of attack of airplane

V_A measured airspeed

V_S resultant velocity of airplane in space

V_{AV} vertical component of measured airspeed

V_{SV} vertical component of airplane velocity in space

V_{AH} horizontal component of measured airspeed

V_{SH} horizontal component of airplane velocity in space

V_W component of wind velocity parallel to azimuth direction of flight path

a_n component of acceleration in "g" units acting along the Z axis of the airplane

W gross weight of airplane

From the basic equation for lift,

$$L = Wa_n = \frac{dC_L}{d\alpha} \alpha_a Sq$$

the expression for absolute angle of attack is deduced as

$$\alpha_a = \frac{Wa_n}{\frac{dC_L}{d\alpha} Sq} \tag{1}$$

where

$\frac{dC_L}{d\alpha}$ rate of change of airplane lift coefficient with angle of attack

S wing area, square feet

q dynamic pressure, pounds per square foot

If 95 percent of the value of $\frac{dC_L}{d\alpha}$ measured in wind-tunnel tests of an SBD-1 model is used for the value of $\frac{dC_L}{d\alpha}$ for the SBD-1 airplane in order to account for the effect of perforated flaps, and if q is measured in inches of water, equation (1) becomes

$$\alpha_a = \frac{Wa_n}{0.0725 \times 324 \times 5.2q} = \frac{Wa_n}{122q} \qquad (1a)$$

The angle of attack for zero lift relative to the wing chord line was taken as -2° on the basis of unpublished wind-tunnel measurements. Since the angle of incidence of the wing relative to the thrust axis was 2.5°, the expression for angle of air flight path with the horizontal is

$$\gamma_A = \theta + 2.0 + 2.5 - \alpha_a$$

or

$$\gamma_A = \theta + 4.5 - \frac{Wa_n}{122q} \qquad (2)$$

Values of α_a and γ_A calculated by use of equations (1a) and (2) are shown in the time histories in figures 4 through 9.

With the true velocity and direction of the airplane relative to air known, the air flight paths (assuming no wind-velocity gradient) were determined by step-by-step integration of the horizontal and vertical displacements s up to any time t; that is,

$$s_{AH} = \Sigma_0^t V_{AH} \Delta t = \Sigma_0^t V_A \cos \gamma_A \Delta t \qquad (3)$$

$$s_{AV} = \Sigma_0^t V_{AV} \Delta t = \Sigma_0^t V_A \sin \gamma_A \Delta t \qquad (4)$$

Since the wind velocity was assumed to be horizontal, equation (4) is also the expression for the vertical distance traveled in space. The horizontal distance traveled in space is simply

$$s_{SH} = \Sigma_0^t (V_A \cos \gamma_A + V_W) \Delta t$$

$$s_{SH} = \Sigma_0^t V_A \cos \gamma_A \ \Delta t + \Sigma_0^t V_W \Delta t \qquad (5)$$

Note that the first term on the right-hand side of equation (5) is identical with the right-hand side of equation (3). The second term on the right-hand side of equation (5) gives simply the horizontal distance traveled by the airplane (with respect to the ground) due to the motion of the air through which the airplane is moving.

Flight paths relative to air and space are presented for the six typical dives in figures 11 through 16. Time increments during which velocity and angle were assumed constant had a value of 1 second. The first point shown on each path corresponds to zero time, the second to 1/2 second, the third to $1\frac{1}{2}$ seconds, the fourth to $2\frac{1}{2}$ seconds, and so forth. Data used in flight-path calculations were taken from original instrument records rather than from time histories in order to preserve accuracy.

Relative attitude angles or air flight-path angles between any two times during a particular dive are estimated to be accurate to within ±1°. Absolute values of these angles for any dive are estimated to be accurate to within ±2°. The length of any air flight path is estimated to be accurate to within ±2 percent. Comparable values for space flight-path accuracy cannot be definitely stated since exact wind conditions existing during each dive were not known.

The discrepancies which were found between loss in measured pressure altitude and loss in calculated geometric altitude are attributed for the most part to difficulty in obtaining exactly correct initial attitude angles by means of pendulum inclinometer readings. It is noteworthy that in flights 1 and 2, where the correlation of initial angles was best, the average difference between altitude losses for nine dives was 1.67 percent of the loss in measured pressure altitude as compared with 2.92 percent for the nine dives made in flight 3. The slight error in airspeed measurements, as well as the deviation in ambient pressure against altitude relationships from standard conditions, also contributed to these discrepancies.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

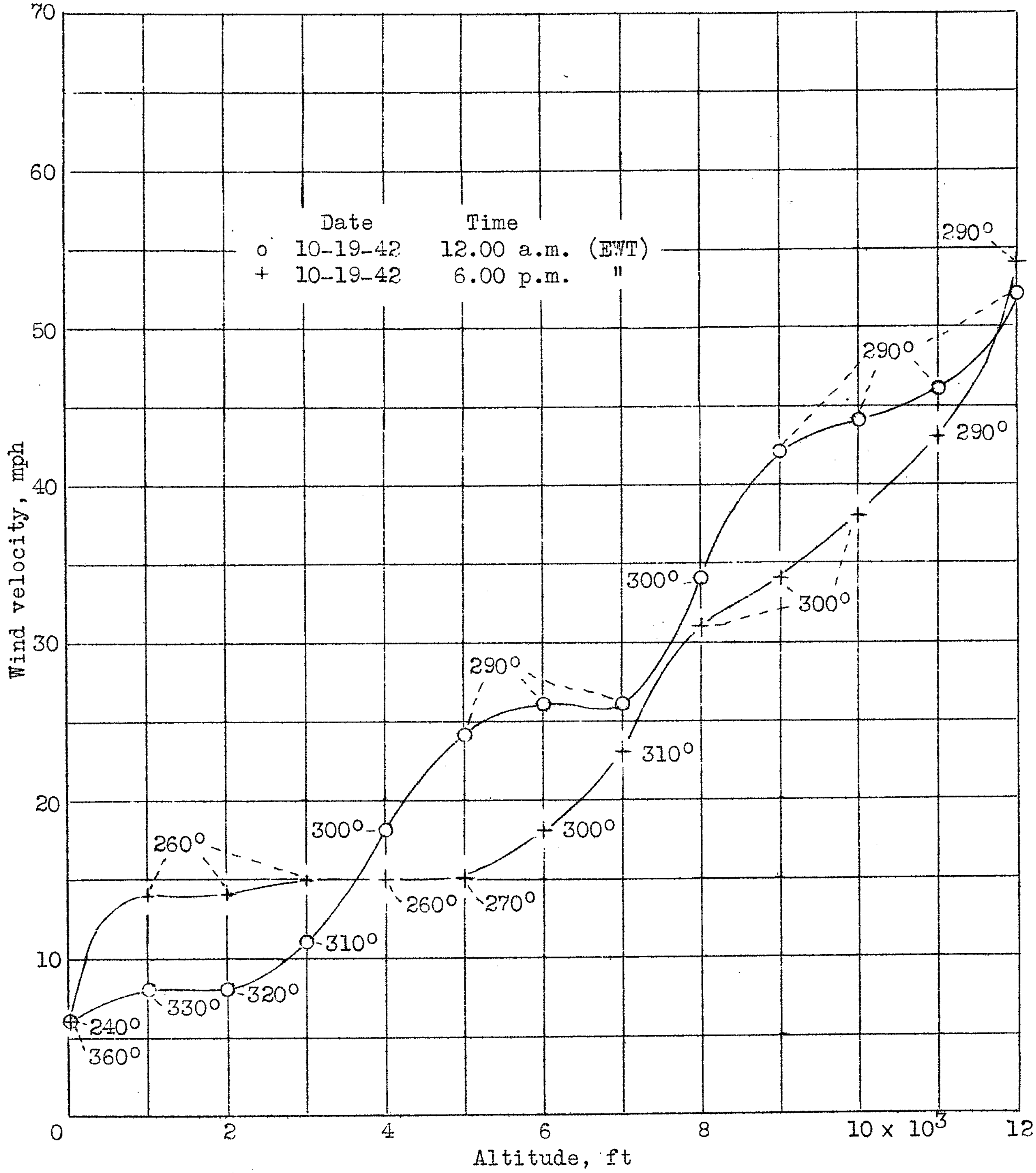
REFERENCE

1. Wildhack, W. A.: Pressure Drop in Tubing in Aircraft Instrument Installations. T.N. No. 593, NACA, 1937.

TABLE I

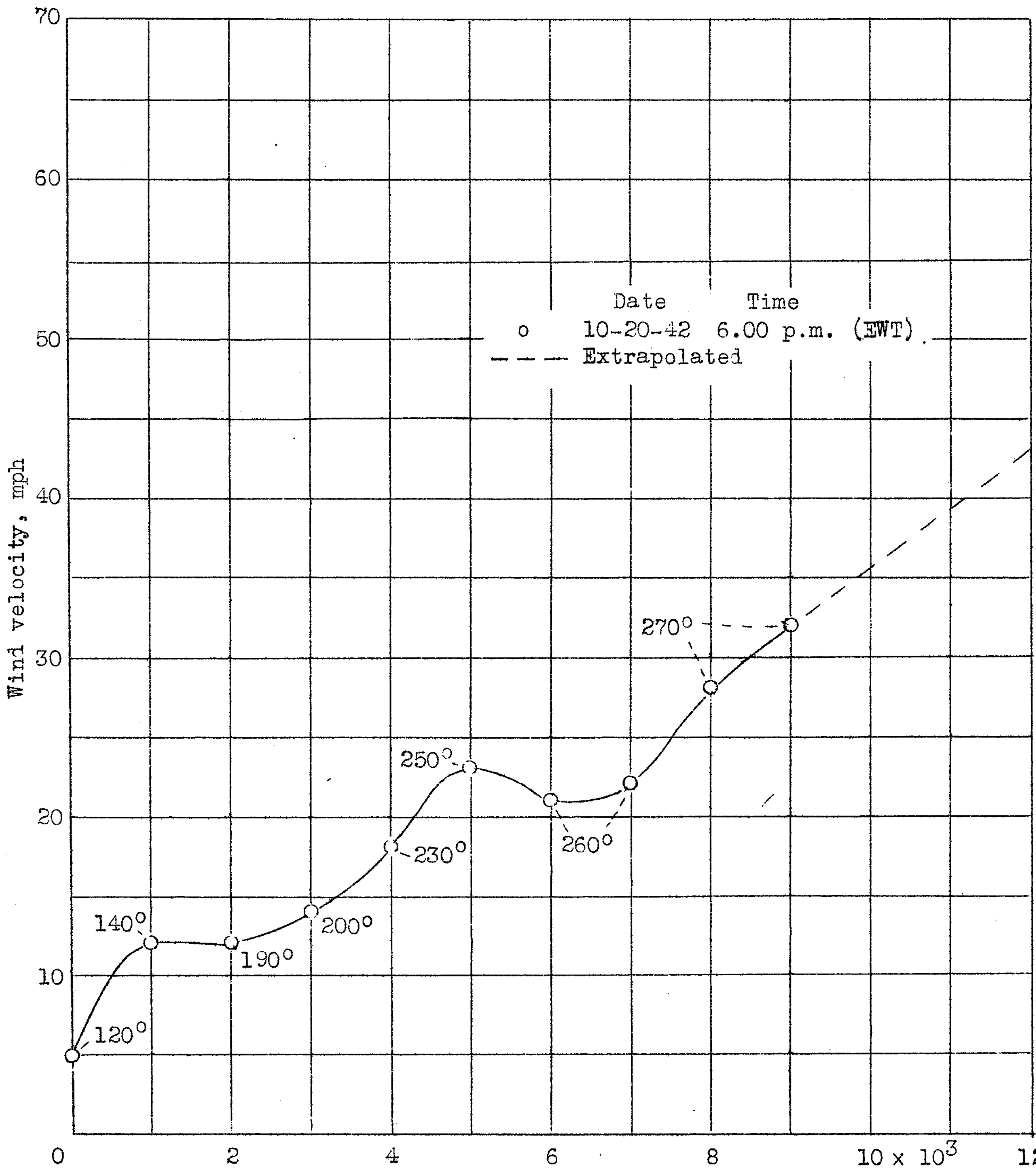
AIRPLANE CONDITIONS AND RESULTS OF DIVE TESTS WITH SBD-1 AIRPLANE

Pilot	Flight and run	Date	Time of dive (Eastern War Time)	Airplane gross weight, W (lb)	Reference dive direction (deg azimuth)	Estimated maximum deviation from reference direction (deg)	Estimated angle of dive (deg)	Measured space dive angle (deg)	Loss in standard pressure altitude (ft)	Loss in geometric altitude (ft)	Difference in altitude loss (per cent of loss in standard pressure altitude)	Figure showing time history of motion	Figure showing air and space flight paths
	1-1		12:50 p.m.	7450	270	±30	45	43	3430	3335	2.8		
	1-2		12:56	7420	270	±30	45	41	3310	3278	1.0	4	11
	1-3		1:04	7380	270	±30	45	43	3530	3576	-1.3		
	1-4		1:11	7350	270	±30	60	61	2820	2839	-0.7		
A	1-5	10/19/42	1:16	7330	270	±30	60	55	3450	3515	-1.9	5	12
	2-1		3:41	7490	320	±30	60	54	4000	3891	2.7		
	2-2		3:49	7450	320	±30	75	58	5290	5192	1.9		
	2-3		3:55	7420	320	±30	75	60	6120	6032	1.4		
	2-4		4:10	7360	320	±30	75	66	7520	7615	-1.3	6	13
	3-1		4:22	7480	330	±15	75	70	6400	6569	-2.6	7	14
	3-2		4:30	7450	330	±15	75	69	4680	4757	-1.6		
	3-3		4:39	7400	330	±15	75	74	4310	4453	-3.3		
	3-4		4:46	7370	330	±15	60	61	3750	3923	-4.6		
B	3-5	10/20/42	4:53	7340	330	±15	60	61	4070	4154	-2.1	8	15
	3-6		4:59	7310	330	±15	60	62	3870	3669	-5.2		
	3-7		5:05	7280	330	±15	45	44	2280	2338	-2.5		
	3-8		5:10	7260	330	±15	45	47	2900	2974	-2.5		
	3-9		5:15	7240	330	±15	45	48	2410	2364	1.9	9	16



(a) Wind measurements before flight 1 and after flight 2.

Figure 1(a,b).- Atmospheric wind conditions for SBD-1 dive tests as measured at Norfolk, Va. Wind direction in degrees azimuth indicated along curves.



(b) Wind measurements taken after flight 3.

Figure 1.- (Concluded)

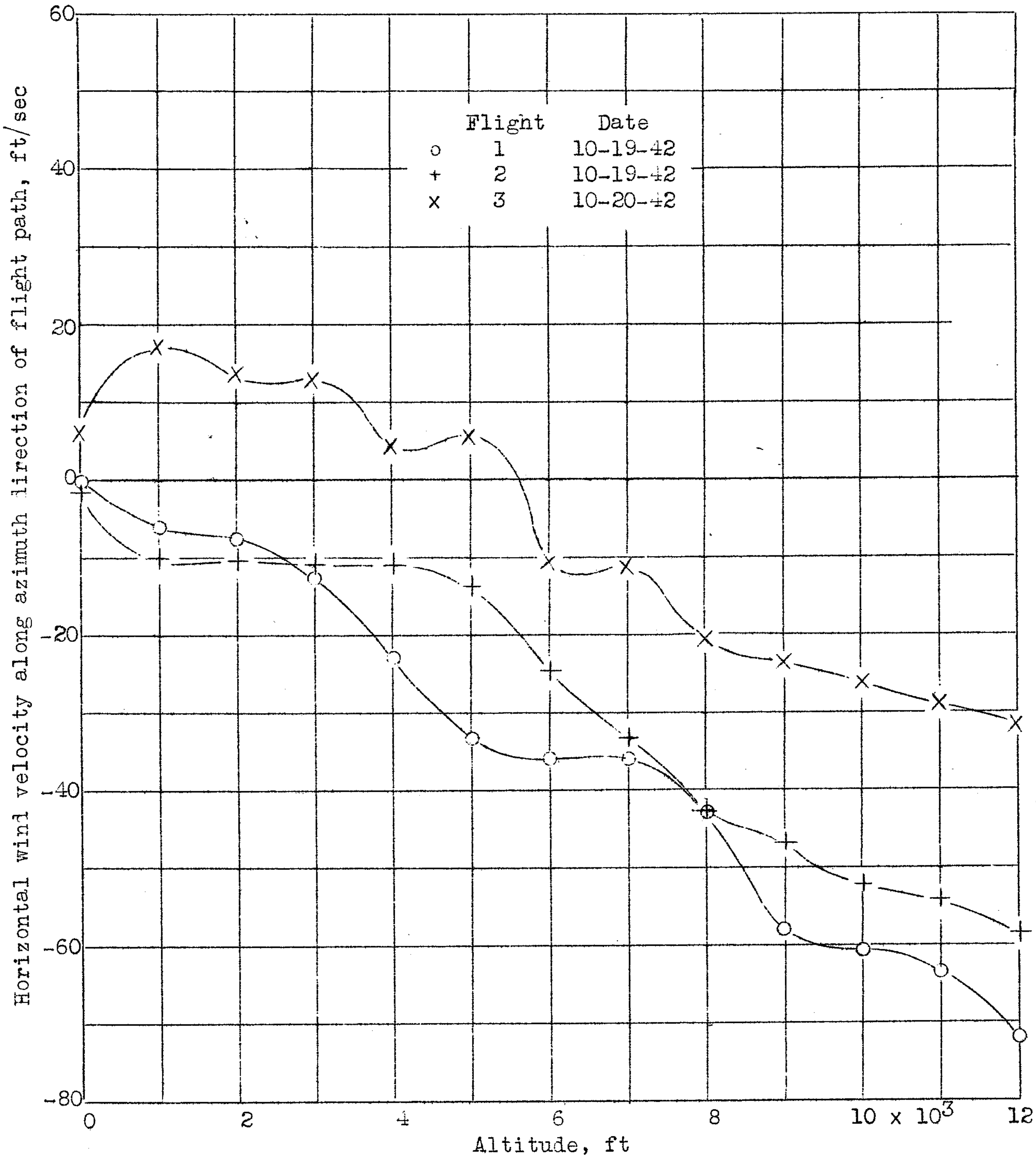


Figure 2.- Variation of wind velocity along azimuth direction of the flight path with altitude for SBD-1 dive tests.

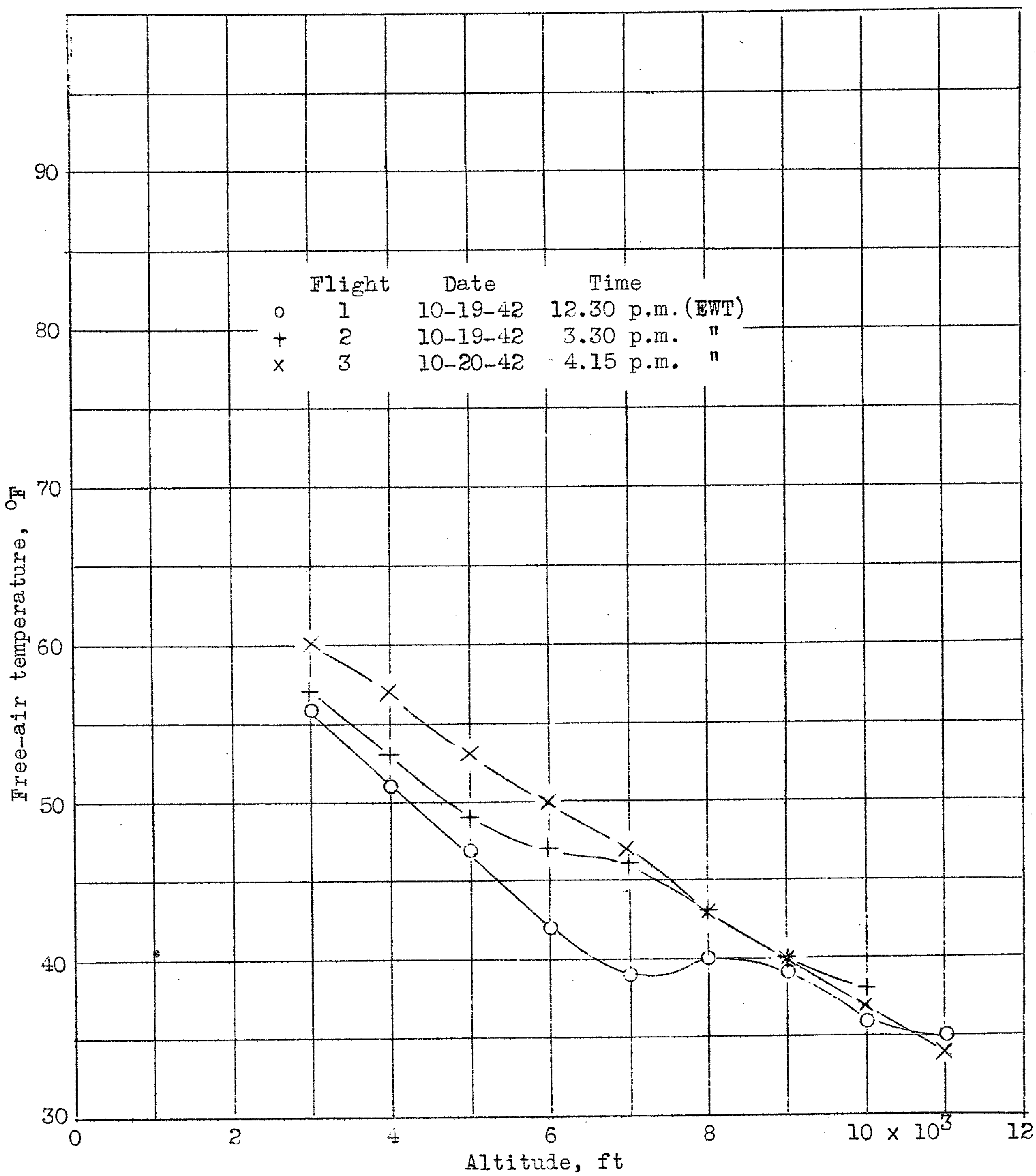


Figure 3.- Variation of free-air temperature with altitude during SBD-1 dive tests.

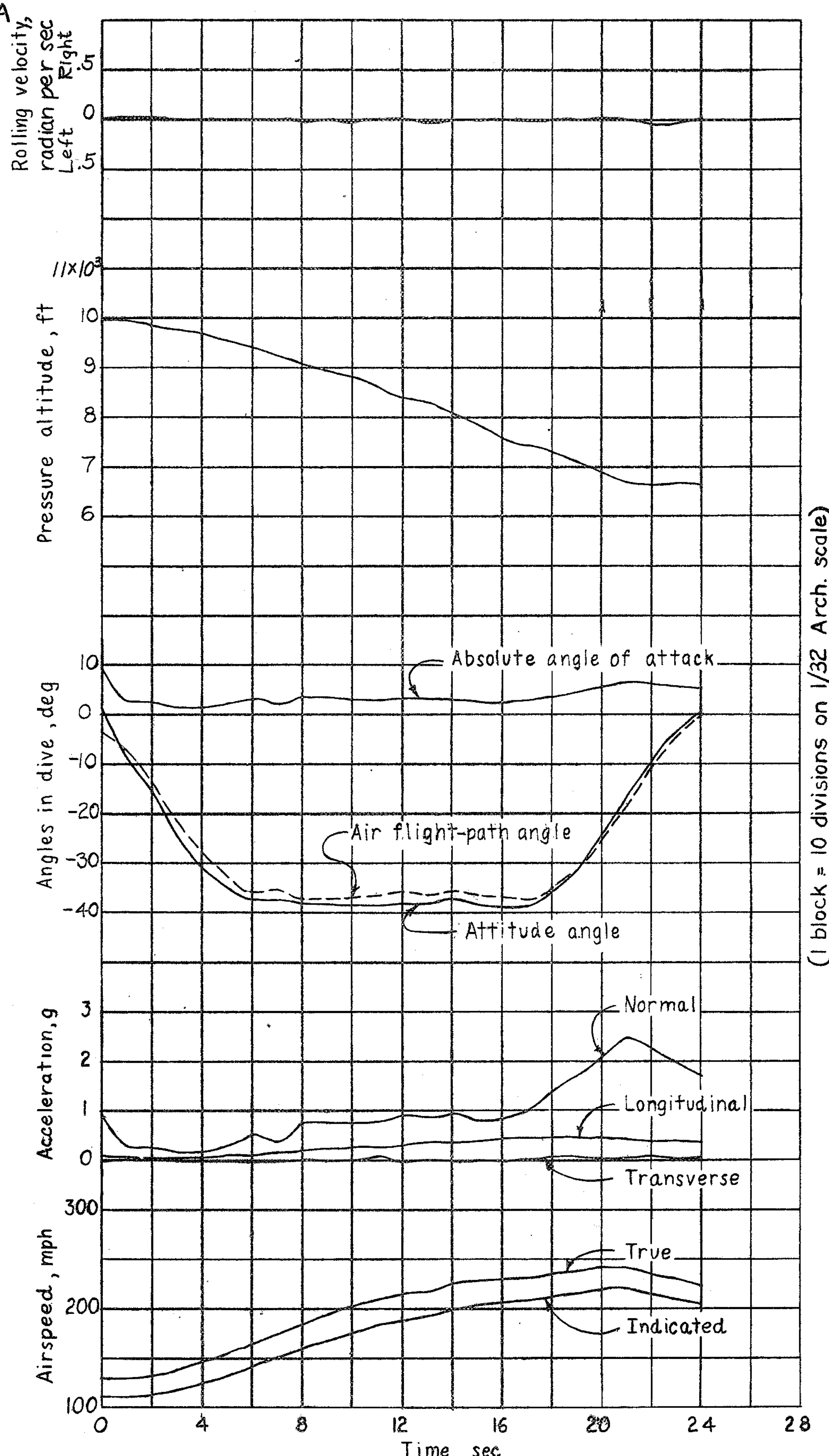


FIGURE 4. - TIME HISTORY OF ESTIMATED 45° DIVE MADE WITH SBD-1 AIRPLANE. FLIGHT 1, RUN 2; PILOT A.

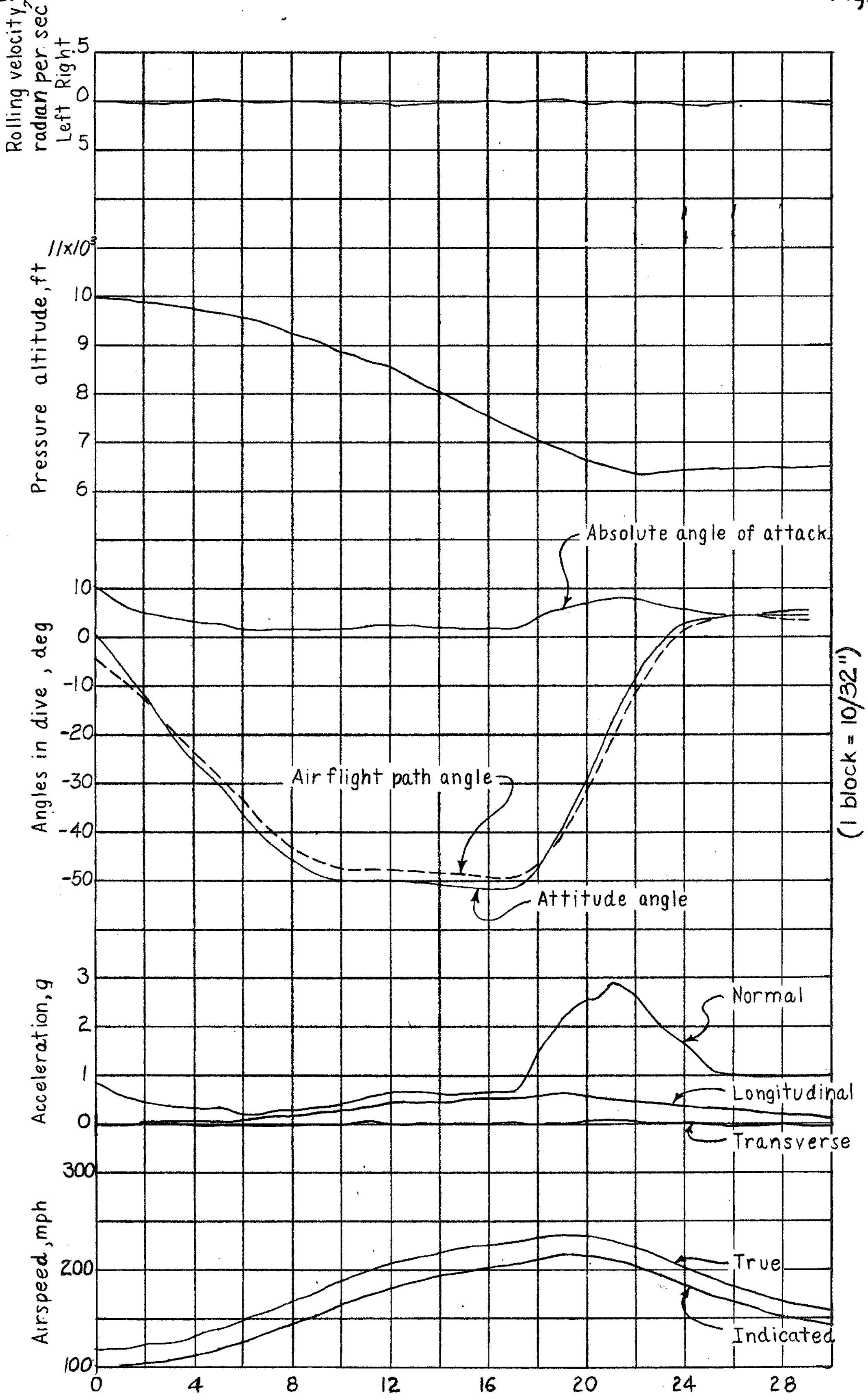
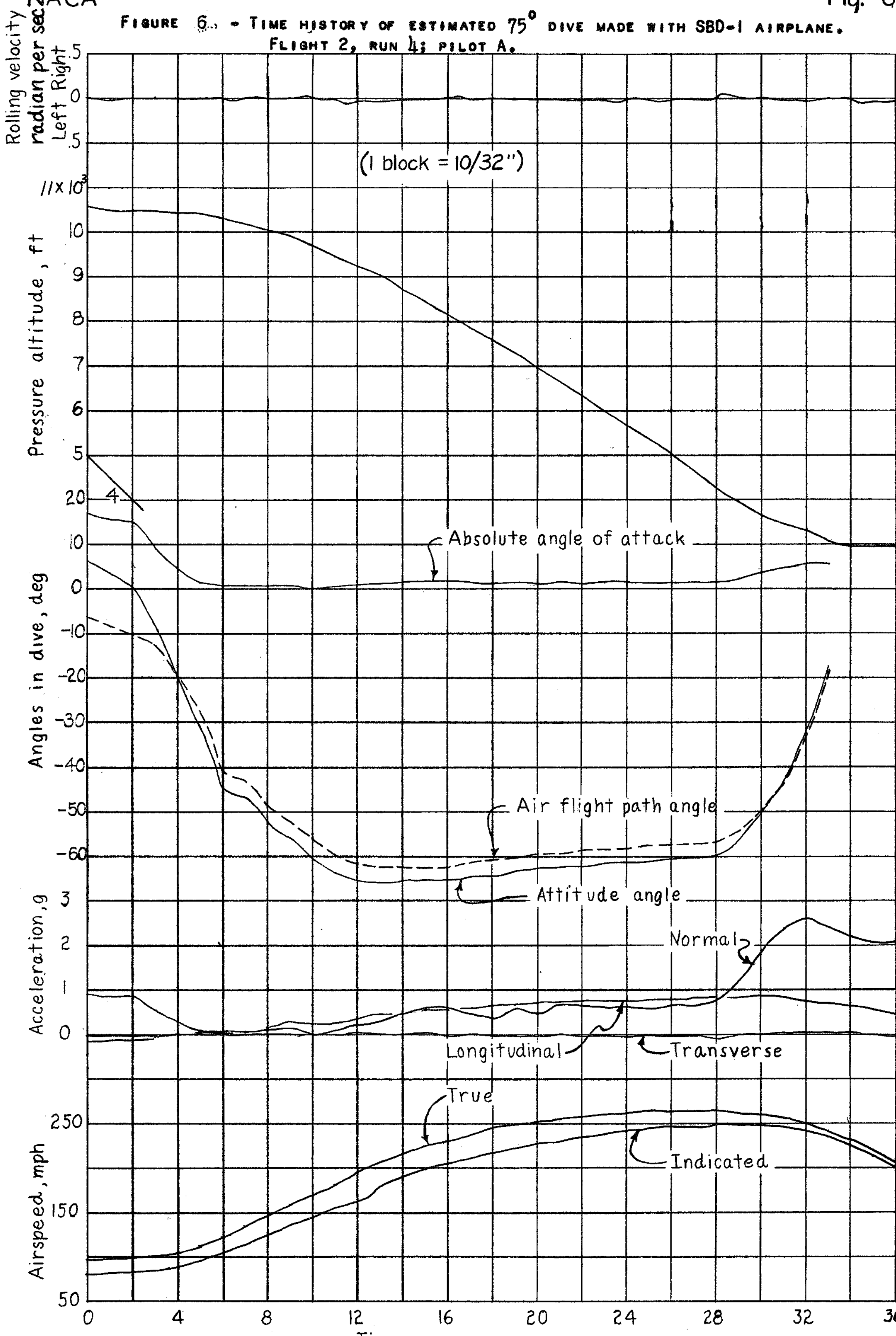


FIGURE 5. - TIME HISTORY OF ESTIMATED 60° DIVE MADE WITH SBD-1 AIRPLANE.

FIGURE 6. - TIME HISTORY OF ESTIMATED 75° DIVE MADE WITH SBD-1 AIRPLANE. FLIGHT 2, RUN 4; PILOT A.



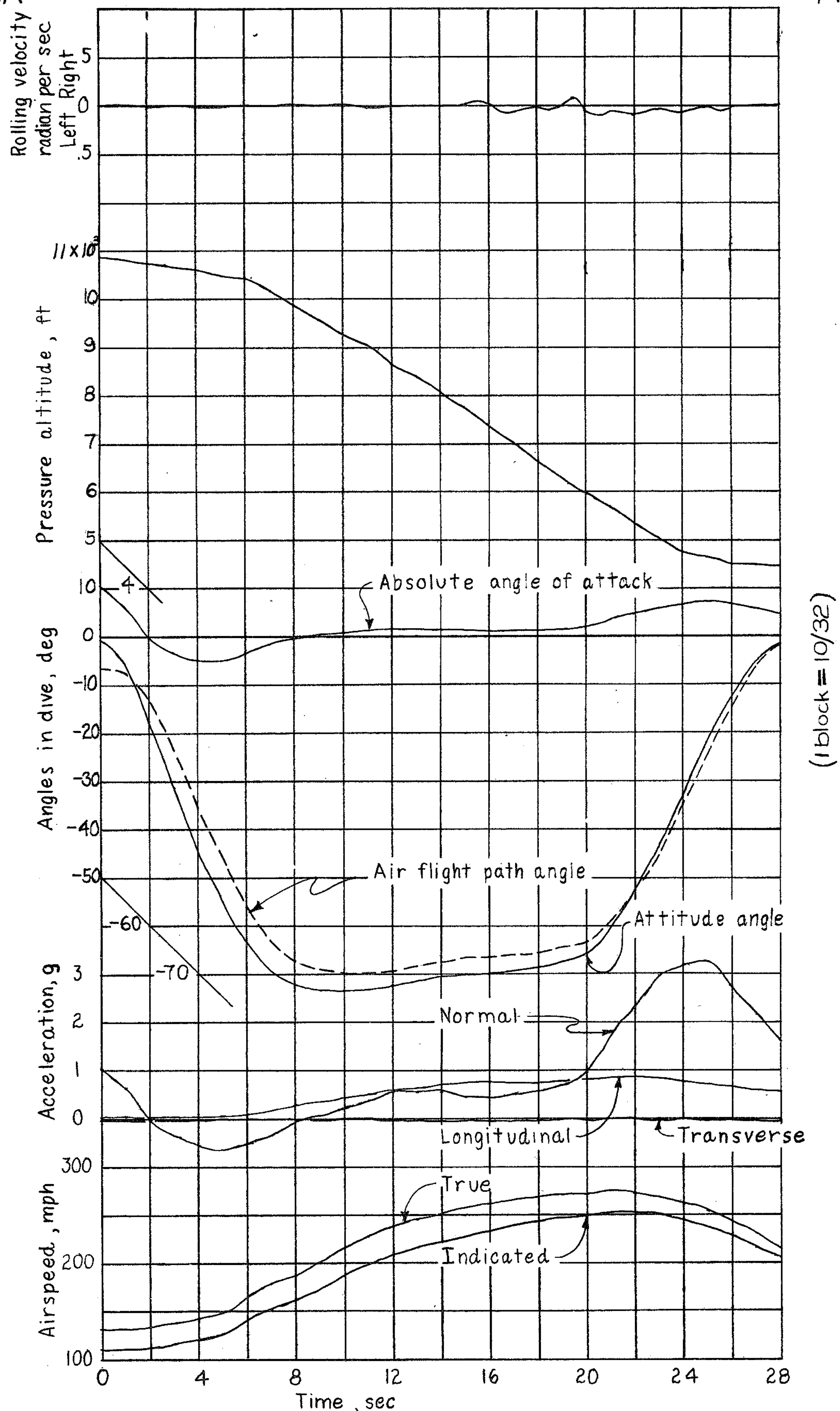


FIGURE 17. - TIME HISTORY OF ESTIMATED 75° DIVE MADE WITH SBD-1 AIRPLANE. FLIGHT 3, RUN 1; PILOT B.

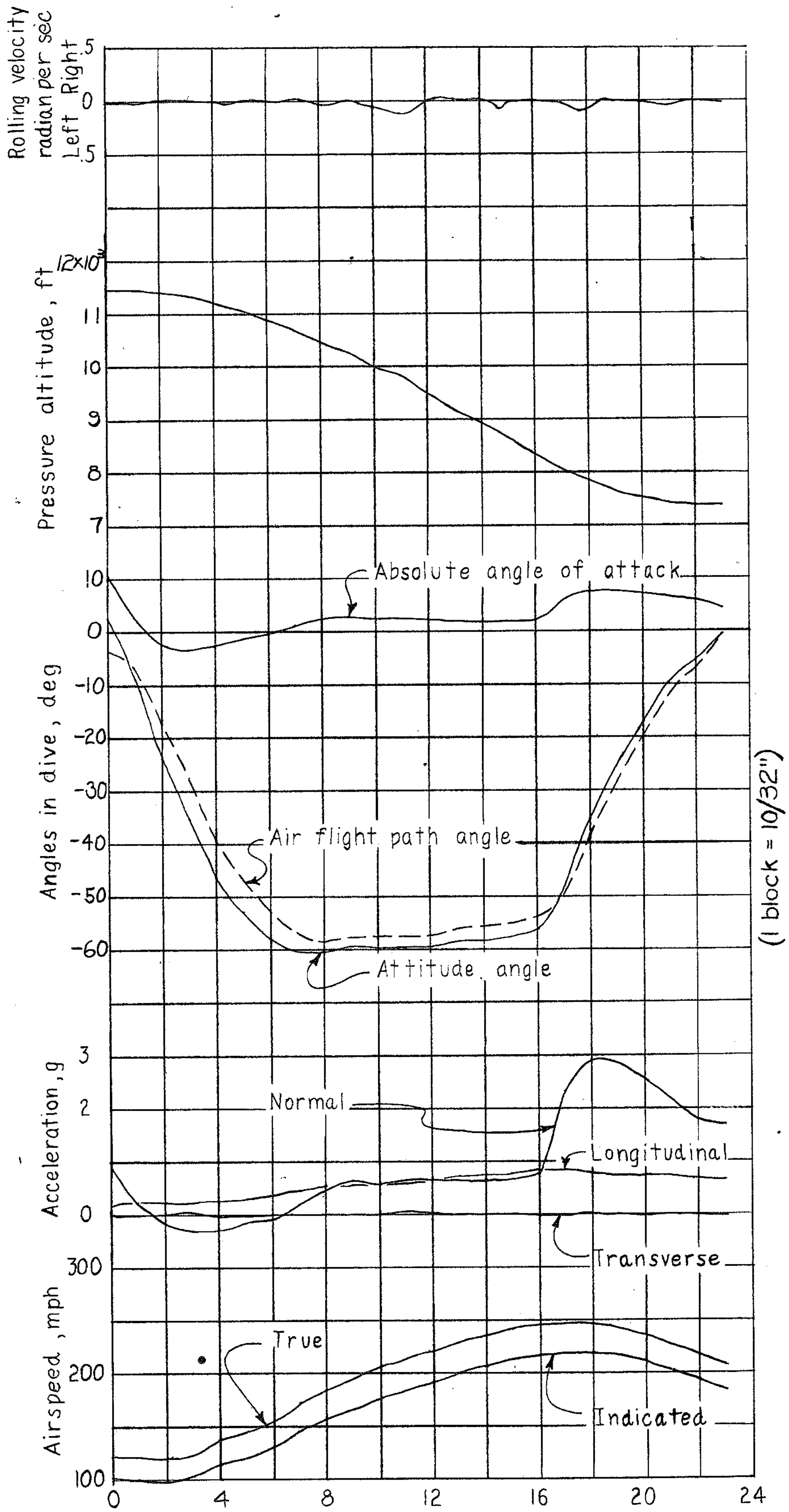


FIGURE 8. - TIME HISTORY OF ESTIMATED 60° DIVE MADE WITH SBD-1 AIRPLANE. FLIGHT 3. RUN 5: PILOT B.

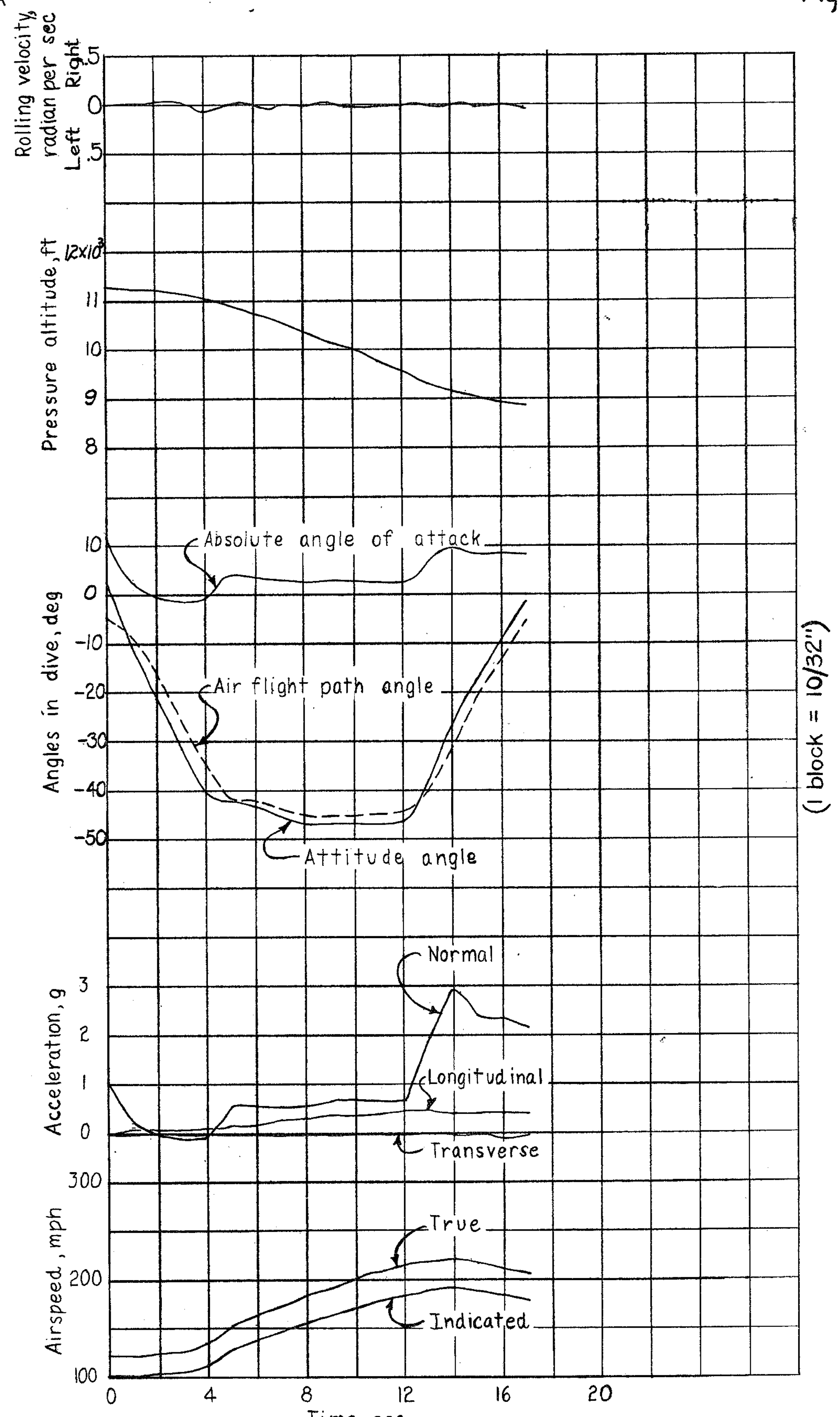


FIGURE 9. - TIME HISTORY OF ESTIMATED 45° DIVE MADE WITH SBD-1 AIRPLANE.

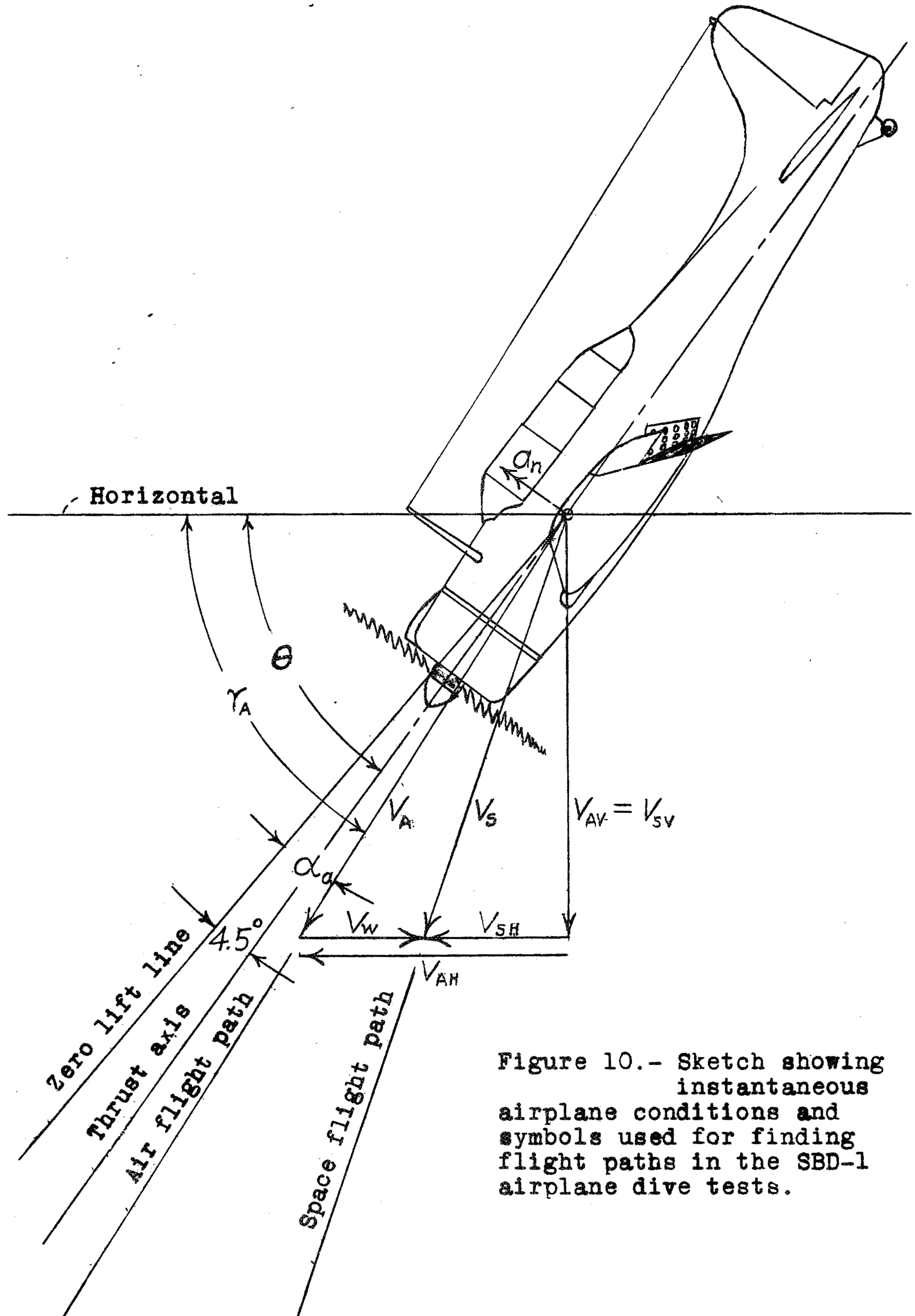


Figure 10.- Sketch showing instantaneous airplane conditions and symbols used for finding flight paths in the SBD-1 airplane dive tests.

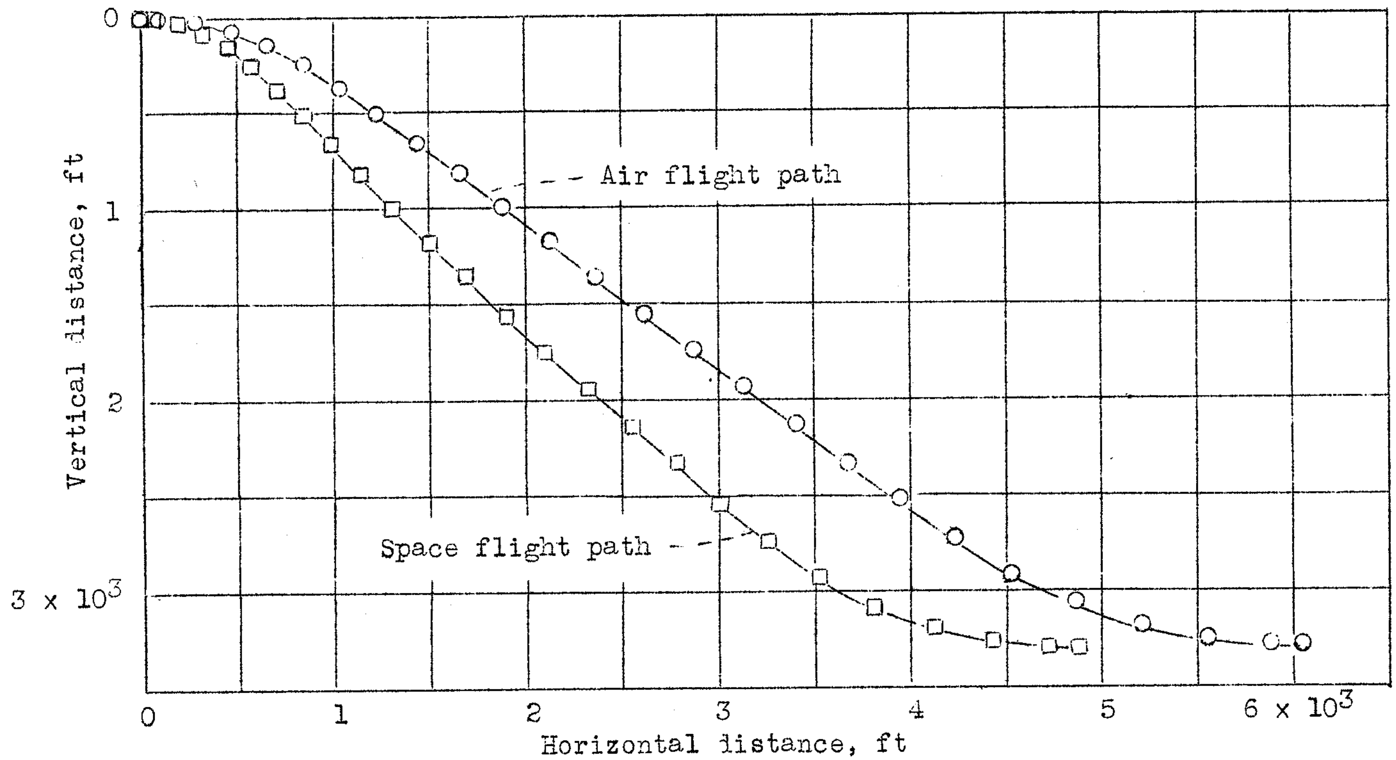


Figure 11.- Flight paths for estimated 45° dive of SBD-1 airplane by pilot A in flight 1, run 2.

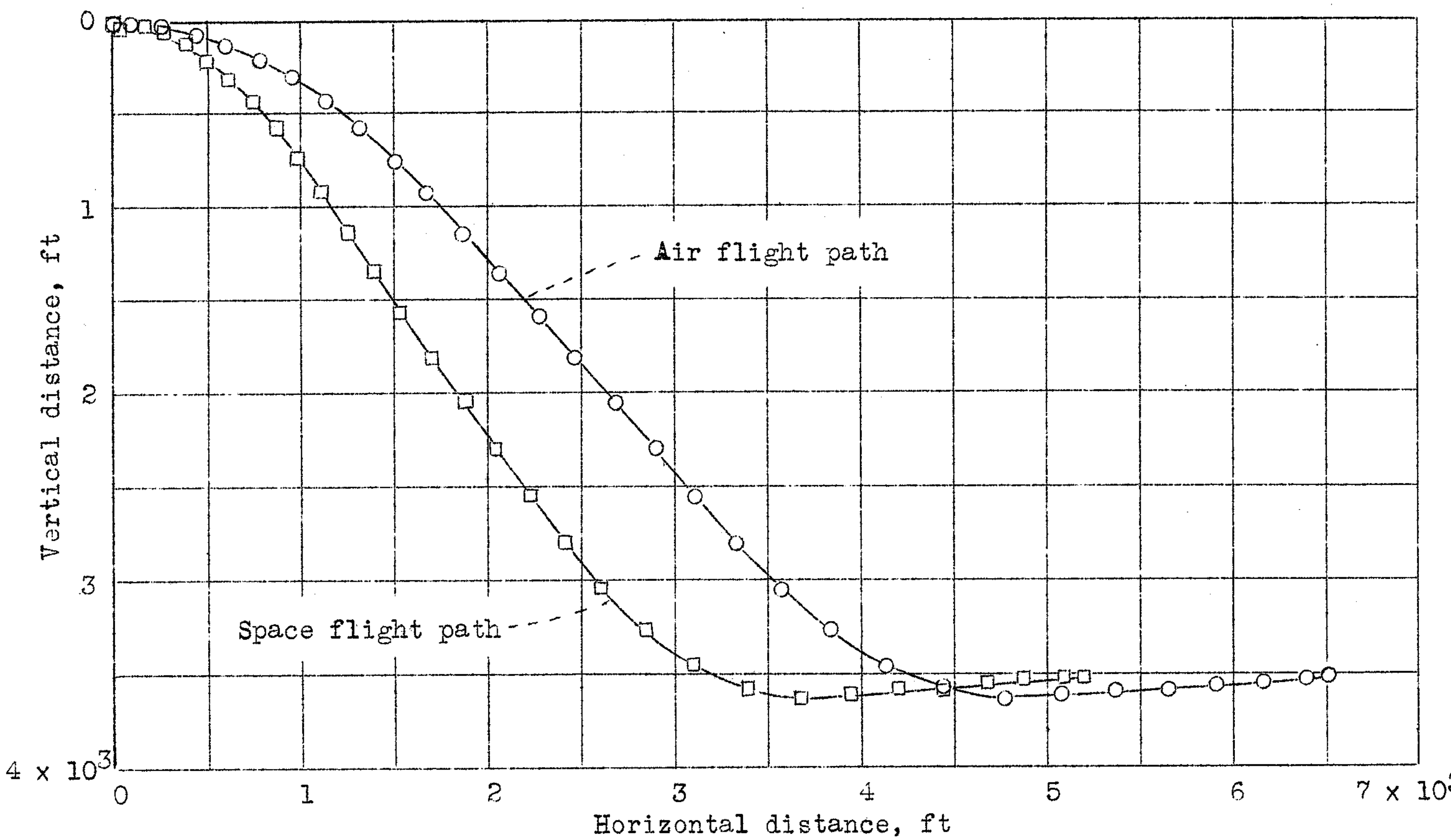


Figure 12.- Flight paths for estimated 60° dive of SBD-1 airplane by pilot A in flight 1, run 5.

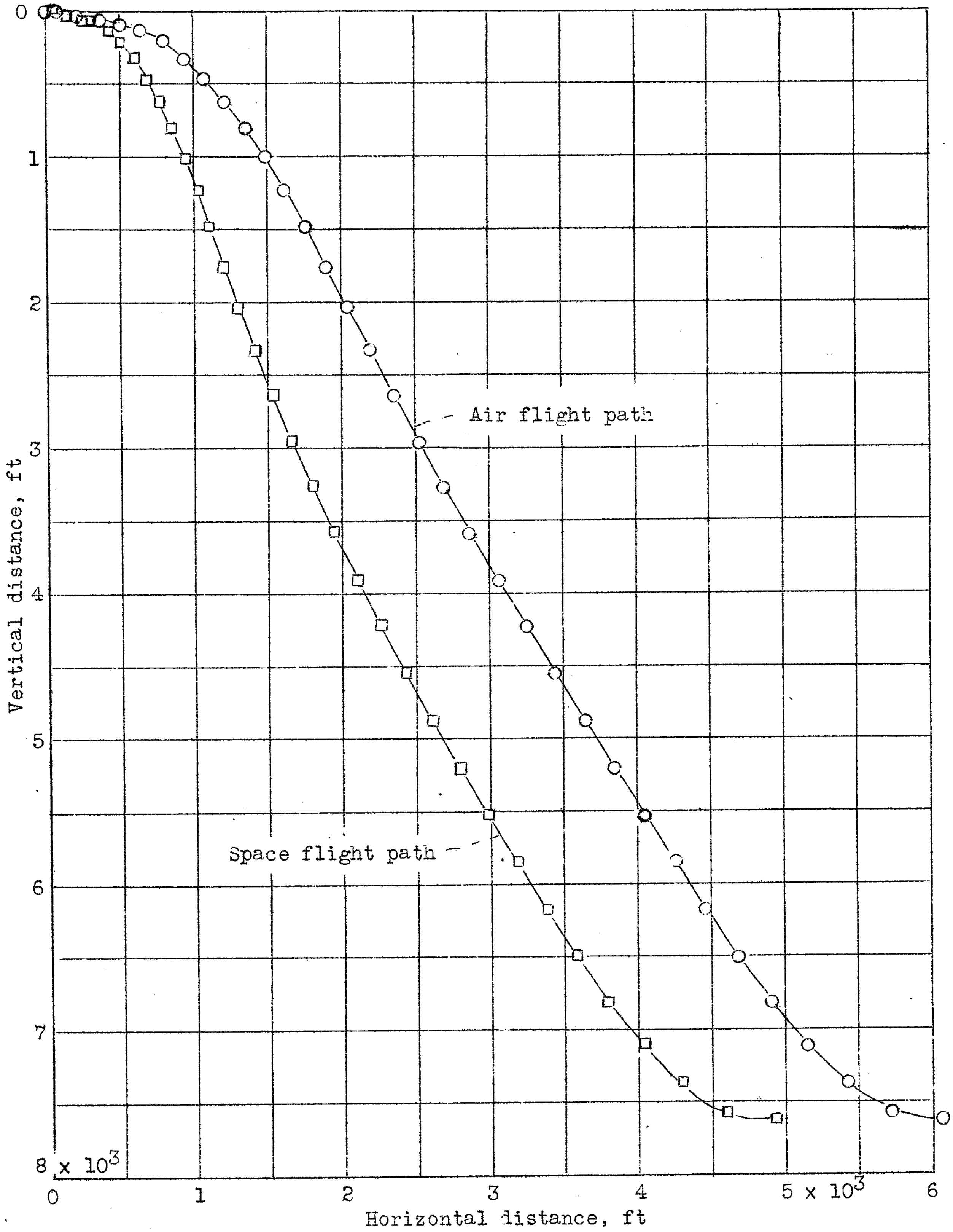


Figure 13.- Flight paths for estimated 75° dive of SBD-1 airplane by pilot A in flight 2, run 4.

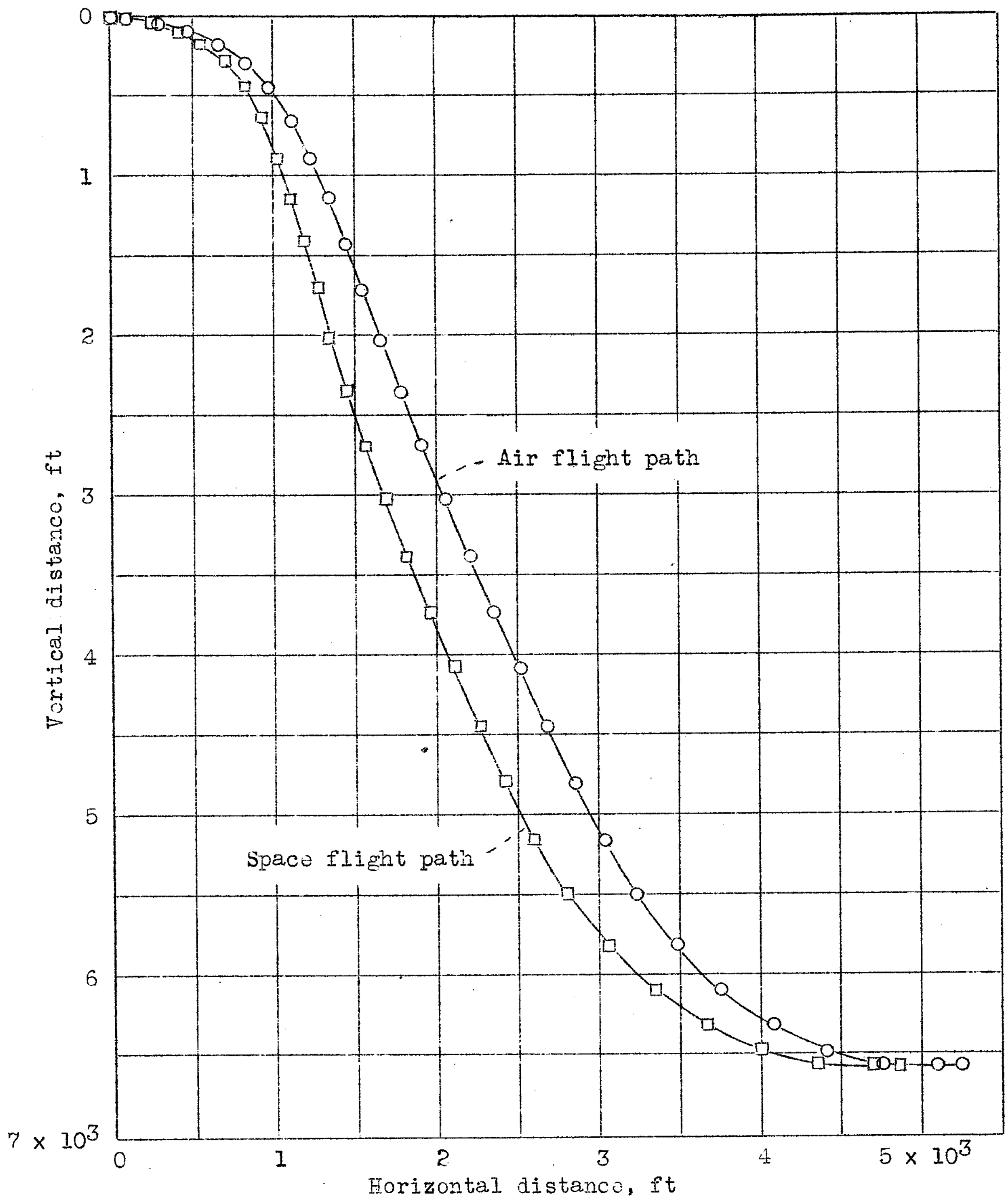


Figure 14.- Flight paths for estimated 75° dive of SBD-1 airplane by pilot B in flight 3, run 1.

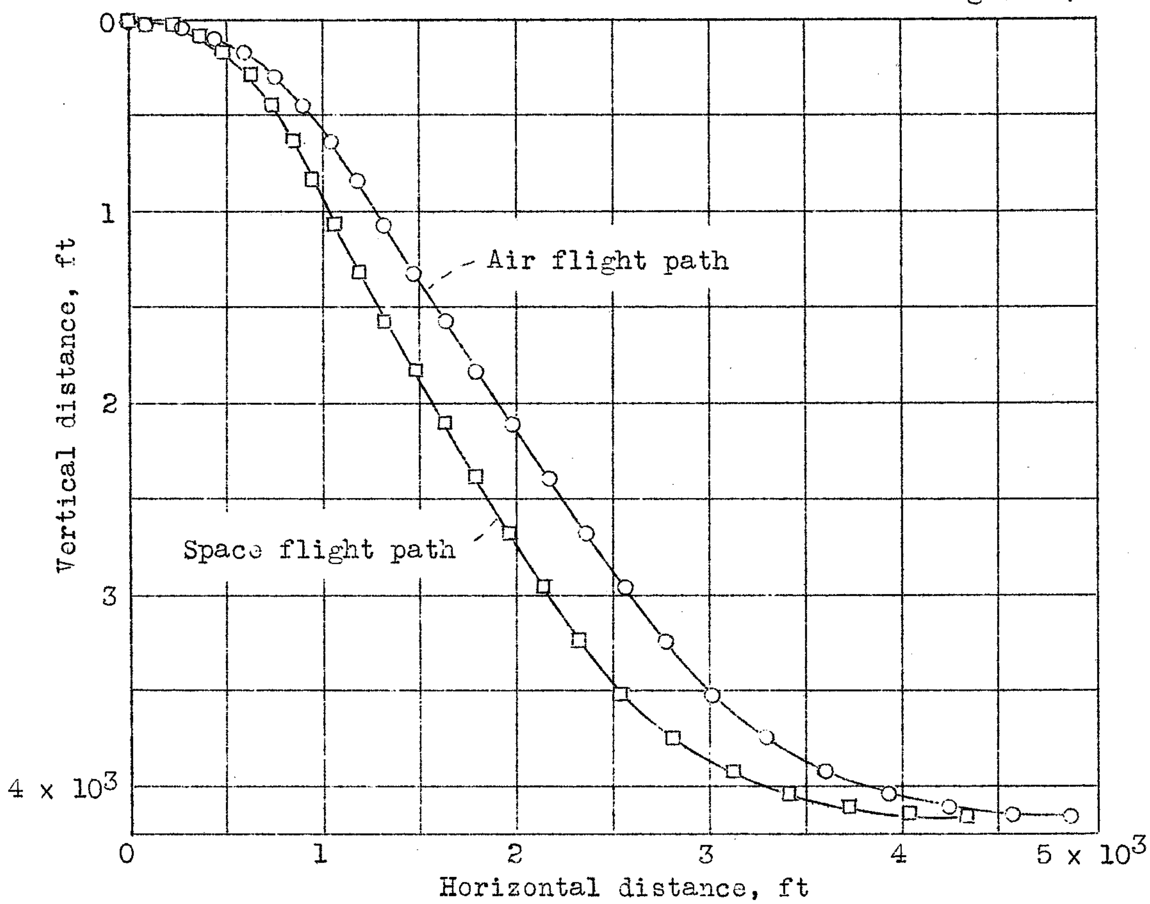


Figure 15.- Flight paths for estimated 60° dive of SBD-1 airplane by pilot B in flight 3, run 5.

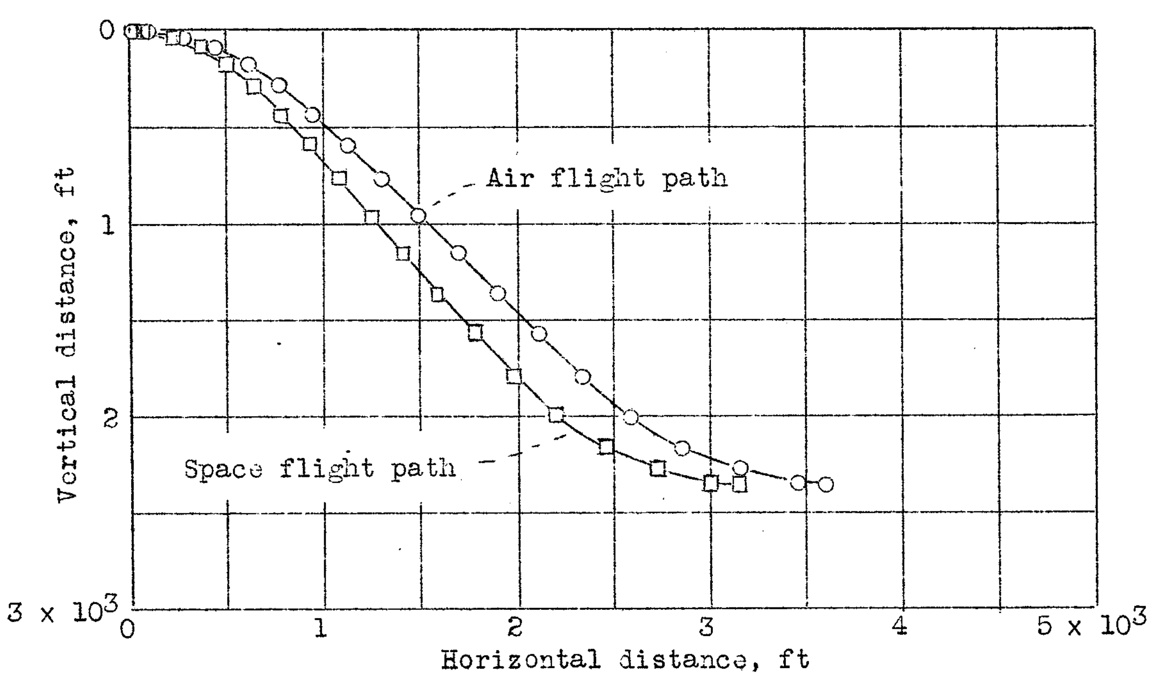


Figure 16.- Flight paths for estimated 45° dive of SBD-1 airplane by pilot B in flight 3, run 9.